Can We Believe in a Purely Unitary Quantum Dynamics?

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Abstract. It is pointed out that the question of a purely unitary quantum dynamics amounts to the question if von Neumann entropy of a dynamically closed quantum system is preserved in evolution.

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Without Schlosshauer's recent critical analysis of relevant experiments [1] showing that the thesis from the title is not refuted sofar the question from the title could not be asked. The author of these lines proposes a "YES" answer. This short note should give some theoretical reasons for it.

Some remarkable results of Davies [2] (see Theorems 3.1 and 3.4 in Chapter 2 there) can be viewed, as easily seen, in the following manner:

Purely unitary dynamics of a quantum system that does not interact with its environment **is equivalent to** *the following four assumptions:*

(i) The dynamical law can be expressed as a single-valued and time-dependent **map** *in the set of density matrices of the quantum system.*

(ii) The map **preserves mixtures** *(mathematically: preserves convex combinations).*

(iii) The map **preserves pureness** *of a state.*

(iv) The map is **continuous in time**.

Once this is recognized, the question from the title can be changed as follows: *Is There Theoretical Reason to Believe in the Four Mentioned Requirements?*

If one believes that density operators and only they express quantum states, then requirement (i) sounds natural. An alternative to (i) would be allowing two different mixtures making up the same density matrix to evolve dynamically into different density matrices. Gisin has shown [3] that this brings us into conflict with with the special relativity theory (which, in turn, deserves believing in).

Density matrices may describe ensembles, and these can be thought of as being suitable sets of individual quantum systems. The latter evolve each separately, and violation of requirement (ii) would, as easily seen, make nonsense of this idea (in view of the fact that sets can be thought of as being composed of subsets in different subjective ways).

Requirement (iii) can be understood as saying that once we have complete information on a system, without interaction, we will never lose it.

Violation of requirement (iv) would introduce discontinuities in the evolution, and these would be hard to understand in view of the homogeneity of the time axis.

It seems to me that the given discussion of requirement (iii) needs elaboration.

A modified view of Davies' theorems would keep requirements (i), (ii), and (iv) intact, and replace (iii) by the following:

(iii)' The von Neumann **entropy does not change** *in evolution of a dynamically isolated quantum system.*

It is obvious that (iii)' implies (iii). Conversely, (iii), in conjunction with the other three requirements, gives unitary evolution due to Davies' theorems, and unitary

evolution preserves entropy, i. e., (iii)' is valid.

Thus, to my mind, the question from the title boils down to asking ourselves if we can believe in preservation of entropy, unless interaction changes it. The alternative is spontaneous change of entropy. (Peres has pointed out [4] that entropy can even decrease in non-unitary dynamics.)

I believe in the idea that if entropy changes, one may look for the interaction that causes it. Take the interesting article by Partovi [5], in which, following the important observation in the preceding literature (see *ibid.*) that entropy increase can only occur for open systems, it is demonstrated that purely unitary quantum dynamics does imply the second law of thermodynamics. The way I see it, in interaction of parts of a dynamically closed (or isolated) system, the entropy of the parts may increase, though that of the whole is unchanged, on account of the quantum correlations created in interaction. The correlations carry negentropy, i. e., entropy with a negative sign in the decomposition of the entropy of the whole. This negentropy is called "mutual information" in bipartite systems (see, e. g., [6] and the references therein), and it has its straightforward generalizations in multipartite systems .

As it is well known, purely unitary quantum dynamics implies the so-called measurement paradox. This is a problem, and it must be solved. To my mind, switching over to the alternative (violation of the unitary law) is seeking escape from the difficult search for a solution.

References

[1] Schlosshauer M 2005 *Experimental motivation and empirical consistency in minimal non-collapse quantum mechanics* e-print quant-ph/0506199

[2] Davies E B 1976 *Quantum Theory of Open Systems* (London, Academic Press)

[3] Gisin N 1990 *Phys. Lett. A* **143** 1

[4] Peres A 1989 *Phys. Rev. Lett.* **63** 1114

[5] Partovi M H 1989 *Phys. Lett. A* **137** 440

[6] Herbut F 2005 *Mutual information of bipartite states and quantum discord in terms of coherence information* e-print quant-ph/0506160